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Optimization of Malaysia's power generation mix to meet the electricity demand by 2050

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Abstract

The Malaysian Government has been introducing fuel diversification policies over the past decade by considering other sources of fuel such as alternative and renewables into the electricity mix as a measure to lengthen the oil and gas reserves against premature depletion. Since electricity consumption forms about a fifth of the total energy consumption, and directly impacts the country's economy and people's well-being, it is necessary to pay emphasis on Malaysia's long-term power sector planning by identifying sustainable options which will enhance Malaysia's energy security and mitigate climate change. This paper presents an analysis of the long-term power generation options for Malaysia by deploying the integrated MARKAL-EFOM system (TIMES) model. The examined scenarios are business as usual (BAU) and optimized least cost scenarios which include: existing technology, plus renewable, plus nuclear as well as, plus photovoltaic (PV) and storage. The results indicated that Malaysia has sufficient renewable energy resources to meet the projected electricity demand by 2050 and fossil fuels can be fully replaced with electricity sourced from large hydropower and combination of other indigenous sustainable energy sources. The variability issue of renewables can be stabilized with the integration of storage systems into the grid. This analysis also demonstrated that installation of 8.57 GW solar PV panels on existing rooftops combined with 3.6 GW large-scale pumped heat energy storage (PHES) system can generate electricity comparable to a 2.0 GW nuclear plant at a lower system cost of $102.4 billion. Hence, if Malaysia were to adopt a sustainable policy, then nuclear power would not be an ideal option as uranium fuel relies on continuous imports.

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Keywords: Malaysia; Optimization; Power generation mix; Renewable energy; Scenario analysis; TIMES model.

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1. Introduction

The power sector in Malaysia has been heavily dependent on conventional fossil resources, according to 2013 available capacity data indicated that 88.4% came from fossil fuels and 11.4% is from hydropower. To be distinct, the 88.4% accounts for 53.3% natural gas, 30.5% coal, 2.8% fuel oil and 1.8% diesel. The penetration of renewables in the generation mix has been rather laid back despite the implementation of the feed-in tariff and renewable smart targets. The contribution of renewables aside from hydro in the electricity mix in 2013 was only 0.2%[1]. Malaysia is also one of the largest carbon dioxide (CO_2) emitters in South East Asia, ranked third after Indonesia and Thailand. In 2013, the CO_2 emission marked a tremendous four-fold increase to 236.5 Mt compared to 56.6 Mt in 1990. Furthermore, in 2013 power sector alone contributed 54.8% of total CO_2 emissions [2]. Malaysia has also ratified the Paris agreement to reduce 45% of greenhouse gas (GHG) emissions relative to 2005 levels by 2030, in which 35% reduction is on unconditional terms and 10% is upon receipt of climate finance, technology transfer and capacity building from advanced countries. At current production to reserve rate, oil and gas reserves are showing signs of depletion, oil may last for 30 years, while gas may hold about 40 years. Malaysia needs to restructure her electricity generation mix to cater for the aforementioned challenges of climate change and diminishing fossil fuel. As part of the solution, the government has laid plans to commission a 2.0 GW Nuclear Power Plant which is scheduled to be in operation by 2030. Malaysia Nuclear Power Corporation (MNPC) was established and entrusted to lead this initiative, their current focus is to set up the legal framework for nuclear power in the country [3]. Nevertheless, after the Fukushima Daiichi nuclear disaster in 2011, led some European countries to shut down their nuclear reactors as a safety obligation towards their citizens. This incident has enhanced the awareness of the Malaysian public that nuclear technology is associated with inherent risks, and thus the idea of sourcing power from nuclear is no longer intriguing to the public. Thus there is a need to explore other long term sustainable options for power generation in Malaysia. This type of long term foresight studies are still lacking for Malaysia and optimization models are known to be able to provide an objective evaluation of future generation technologies and fuel mix selection. These studies are not only limited to power sector analysis but can cover the whole energy system as well which have been performed by *M.A.H. Mondal et al* (2014), *Mallah and Bansal* (2010) and U.*K. Rout et al* (2011) [4-6]. However, these studies are often unique owing to application of country-specific data, the research objectives may vary upon factors such as policies of national interest, demand or technology-driven or maybe linked to environmental concerns. Hence, this study will assess the optimized least cost selection of future power generation technologies in Malaysia for a period from 2013 until 2050 by evaluating a few scenarios namely the optimized least cost on existing technology, plus renewables, plus nuclear, also plus PV and storage which will be contrasted to the business as usual (BAU) scenario. The electricity demand projection, capacity levels, and electricity generation by technology, the CO_2 emission profile, as well as the total system cost for all scenarios will be presented.

2. Methodology

The methods used in this study involves base year data collection from secondary sources published by the Energy Commission of Malaysia [1]. The growth rates predicted by the Energy Commission as in Table 1 [7] were applied to determine the electricity demand projection up to 2050. The impact of energy efficiency initiatives, higher electricity prices and the slowdown in industrial sales were among the contributing factors to the decreasing trend in electricity demand growth rates. TIMES was selected as the simulation tool for modeling the different scenarios as it is the upgraded version of the MARKAL model. This simulator was developed by the Energy Technology Systems Analysis Program (ETSAP) under the auspices of the International Energy Agency (IEA). TIMES is a specialized energy modeling generator suitable for long term power sector assessment [8]. It is a bottom up, partial equilibrium, linear programming, and least-cost optimization system. Thus, TIMES is an ideal scenario simulator and the perfect tool for foresight analysis. The modeling framework requires the full spectrum of processes from the supply of primary fuels through the conversion technologies to meet the end user demand sectors. The simple reference energy system (RES) for Malaysia is illustrated in Fig. 1.

Table 1. Electricity demand growth rates

Year	Growth (%)
2013	*5.8
2014	*4.3
2015 - 2020	3.1
2021 - 2025	2.6
2026 - 2035	1.4
2036 - 2050	**1.4

* actual **assumed

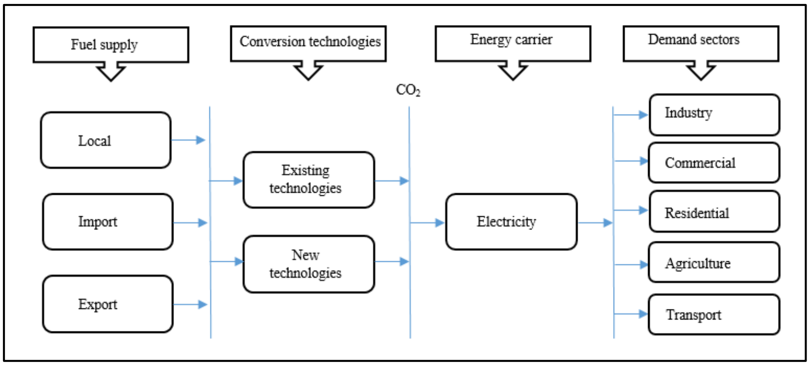

Fig. 1. Reference energy system

General details

All four scenarios were established with following parameters and assumptions:

i) 2013 was designated as base year, as technology stock was compiled from the 2013 energy balance [1];
ii) Study duration commenced from 2013 until 2050;
iii) Milestone reporting period is set at 5-year intervals;
iv) Discount rate was fixed at 3% following the Malaysian Central Bank's discount rate applied over the entire study period;
v) All power plants connected to the grid were considered mainly to emulate the centralized national grid;
vi) It is assumed that consumption of electricity will never exceed generation levels and the electricity demand will increase throughout the study horizon;
vii) No heating load from heat rejected in the energy conversion process was considered in the RES;
viii) National average for transmission and distribution loss for electricity is 4% [9];
ix) Currency was specified in US dollars ($);
x) Primary and secondary fuel costs were obtained from the United States Energy Information Agency [10] ;
xi) Capital, operating and variable cost, as well as the technical efficiencies and availability factor for various technologies, adopted the Energy Technology Reference Indicator 2010-2050 projections [11] and details on PHES was sourced from R. Wardle (personal communication, June 30, 2017);
xii) Electricity from Sarawak hydro resources is assumed accessible to the Peninsular via a High Voltage Direct Current (HVDC) interconnector transmission system;
xiii) Transmission and distribution cost was not accounted in the model;
xiv) Seasonal and daily load fluctuations were not considered; and,
xv) The power sector has no financial constraints due to active investments by the private sector.

Specific details

The evaluated scenarios are defined as follows:

(1) existing technology: Least cost optimization applied to existing technologies cumulated from base year stock with the addition of new committed technologies as planned by the government up to 2035.

(2) plus renewable: Least cost optimization applied to existing technologies plus renewable technologies as in Table 2 which is initiated in the system by 2030, this is to simulate a strong policy impetus on renewables. The methods for renewable energy potential assessment in Malaysia will be described in a separate paper.

(3) plus nuclear: Least cost optimization applied to existing technologies plus 2.0 GW cumulated nuclear power by 2030, this is to simulate the government's plan to adopt nuclear power in the electricity mix.

(4) plus PV and storage: Least cost optimization applied to existing technologies plus 8.57 GW PV combined with cumulated 3.59 GW large scale PHES system which commences by 2030. This is to reflect the capability of PV coupled with PHES system that could generate comparable levels of electricity to a 2.0 GW nuclear plant.

(5) business as usual: This scenario presents the existing technologies cumulated from base year with the addition of new committed technologies up to 2035 as planned by the government and this trend is maintained up to 2050. Power plant capacities are fixed throughout the study period except for certain technologies that have been identified to retire early from the system.

Table 2. Renewable potential (upper bound)

Technology	Power capacity (GW)
Photovoltaics	14.130
Offshore wind	2.000
Geothermal	0.069
Tidal stream	0.185
Hydropower	31.531
Biomass	1.181
Biogas	1.103

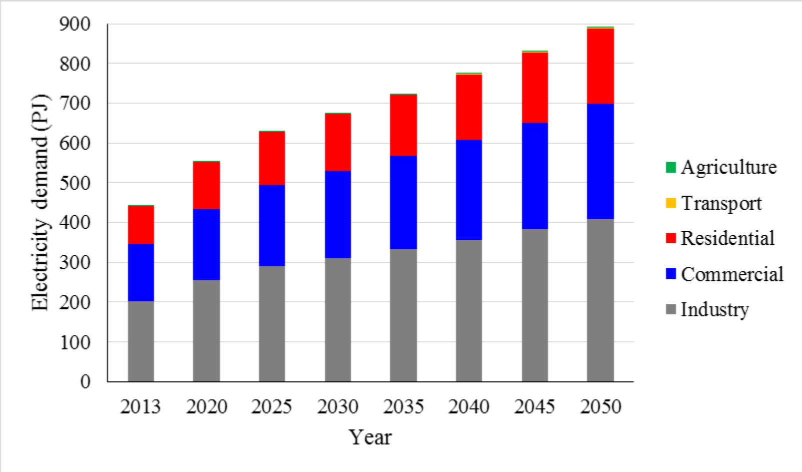

Fig. 2. Electricity demand projection by sector

3. Simulation results and discussion

The results of the assessment will be presented in this order: electricity demand projection, power capacity, and electricity generation classified by technology, CO_2 emission profiles, and total system cost estimates.

3.1 Electricity demand projection

The electricity demand for Malaysia in 2013 stood at 443.07 PJ, and by 2050 the figures are expected to double by 2.02 folds to 893.03 PJ, this value aligns with the world and regional electricity generation outlook. The final electricity demand categorized by sector until 2050 is shown in Fig. 2 and the data are presented in Table 3. Analysis of electricity demand by sector indicated that industrial sector will attribute 45.4% of the overall demand, followed by commercial and residential sector with the corresponding share of 32.7% and 21.4%. Agriculture and transport sector will maintain a collective share of just 0.5%. However, the share for transport and agriculture sector will definitely grow, if there is a policy stimulus which promotes the use of electric vehicles in the country,

Table 3. Electricity demand categorized by sector in PJ

Sector	2013	2020	2025	2030	2035	2040	2045	2050
Industry	201.16	254.68	289.56	310.40	332.75	356.70	382.38	409.90
Commercial	144.89	179.22	203.76	218.43	234.15	251.01	269.08	288.45
Residential	94.82	117.63	133.74	143.37	153.69	164.75	176.61	189.32
Agriculture	1.33	2.22	2.52	2.71	2.90	3.11	3.33	3.57
Transport	0.89	1.11	1.26	1.35	1.45	1.55	1.67	1.79
Total	443.07	554.86	630.84	676.25	724.94	777.12	833.07	893.03

3.2 Capacity levels by technology

The generation capacity for all optimized least cost scenarios is expected to increase from 24.97 GW in 2013 to a range between 45.05 to 58.03 GW by 2050 subject to each scenario as shown in Fig. 3. Generators fueled by diesel and heavy or medium fuel oil (HFO/MFO) are retired from the system beginning 2025, whilst conventional gas and open cycle gas turbine exit the system from 2030 onwards. Combined-cycle gas-fired power plants experience a capacity drop from 38% in 2013 to 6 to 8% share across the least cost scenarios. Coal-fired plants capacity reduces from 31% in the base year to 15 until 20% in 2050. Large hydro capacity showed a huge rise in 2050 in contrast to 11% in 2013, for existing technology it achieved 72%, and correspondingly 47%, 68% and 51% for plus renewable, plus nuclear, and, plus PV and storage scenarios. A notable increase in capacity is observed in the plus renewable, as well as in the plus PV and storage scenarios. The model allocated more PV capacity installations due to the lower efficiency available in PV systems to convert solar energy into electricity.

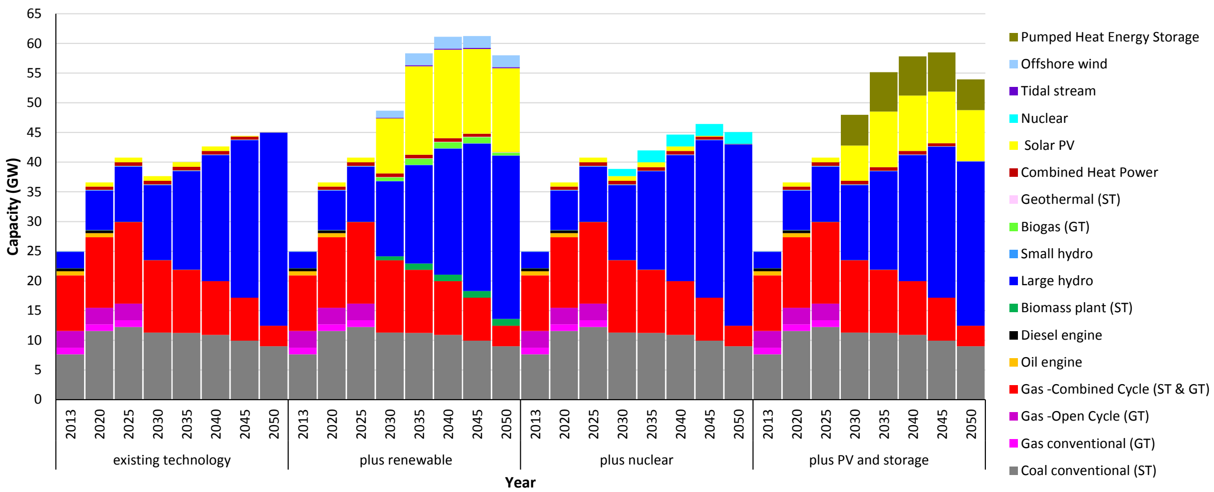

Fig. 3. Capacity levels by technology

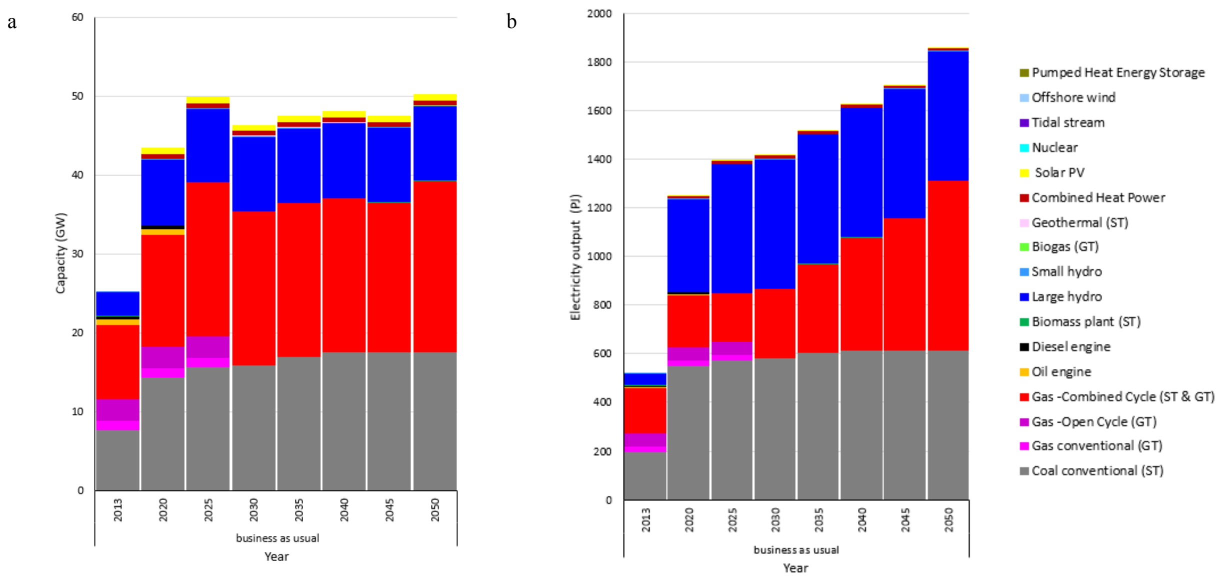

Fig. 4. (a) BAU capacity levels; (b) BAU electricity generation.

Based on Fig. 4(a), the BAU scenario by 2050 reaches a capacity limit of 50.23 GW, a big proportion comprise of coal and combined cycle power plants with a mutual share of 78%, 19% is assigned to hydro power, while 3% is allocated to PV and geothermal.

3.3 Electricity generation by technology

The electricity generation by fuel type in the BAU scenario by 2050 is delivered from 29% hydro, 33% coal, and 38% natural gas as presented in Fig. 4 (b). This scenario is evidently unsustainable since it will require import of natural gas due to the high preservation of fossil fuel in the electricity mix which equals to 71%. The electricity output for all optimized least cost scenarios is summarized in Fig. 5. By 2050, all scenarios projected a dominance of electricity generation from large hydropower: existing technology (100%), plus nuclear (97%), and 92% for the other two scenarios. It is observed that by 2050, the plus renewables scenario rejected biomass and geothermal plants from the system and the generation mix comprises of 92% hydro, 5% PV, 2% offshore wind and 1% biogas. While, in the plus nuclear scenario, nuclear technology supplied 3% of the total electricity and hydro accounted for the balance. Whereas in the plus PV and storage scenario, the model allocated 3% from PV, 5% from stored electricity and 92% from large hydro as the optimized mix.

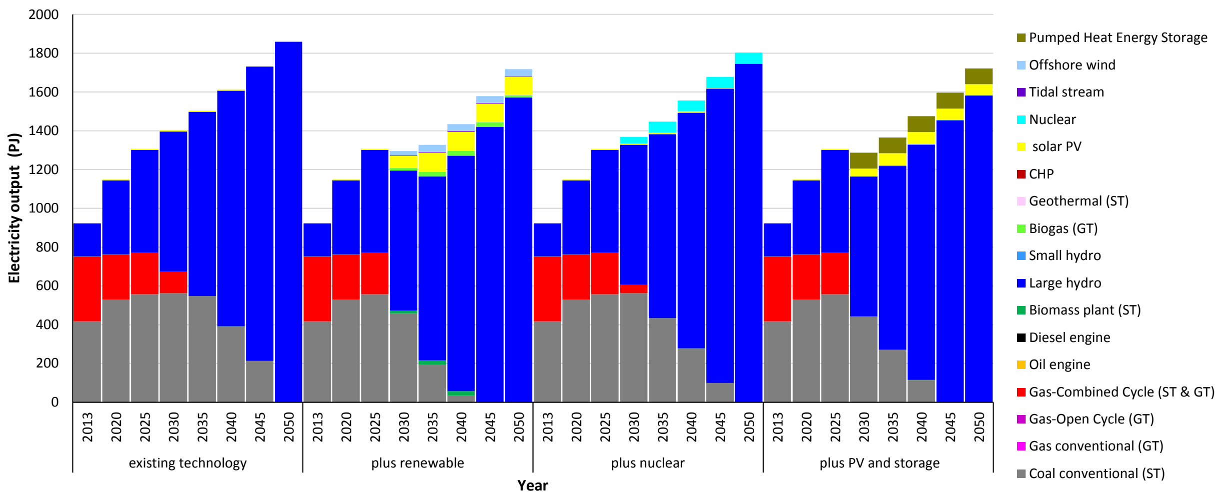

Fig. 5. Electricity generation by technology

3.4 CO_2 emission profile

By 2030 CO_2 emissions are reduced relative to the 2013 levels by 13%, 31%, 17% and 41% for existing technology, plus renewable, plus nuclear and, plus PV and storage scenarios respectively as in Fig. 6. Three scenarios will be totally free from CO_2 emissions by 2050, except for plus renewables scenario that will continue to emit 2% of CO_2 originating from biogas. In 2050, the BAU scenario predicted a 24% increase in CO_2 emissions relative to the 2013 levels. The quickest way to achieve the Paris agreement is by implementing the plus PV and storage scenario, followed by the plus renewable scenario.

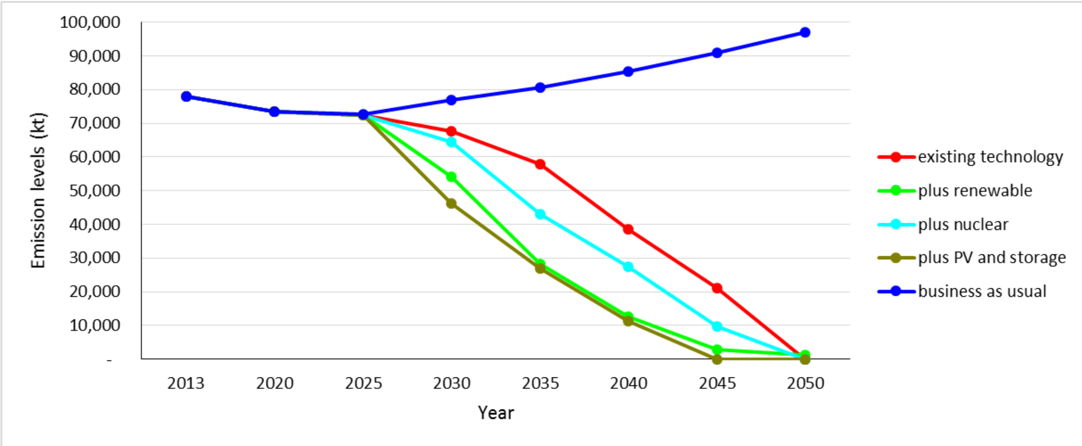

Fig. 6. CO_2 emissions profile

3.5 Total system cost

Comparison of the total system cost across all scenarios is presented in Fig. 7, the model assigned the existing technology scenario with the lowest system cost of $101.5 billion. An increment of 16.5% in system cost was observed in the plus renewable scenario. An interesting finding is that the system cost for plus PV and storage is lesser than the plus nuclear scenario by 2.3%. The higher cost in plus nuclear scenario is due to steady imports of uranium fuel. To comprehend the cost dynamics, it is vital to note that cost of technology will depreciate over time, however, commodity cost will gradually appreciate. The BAU scenario constituted the highest system cost out of all the scenarios.

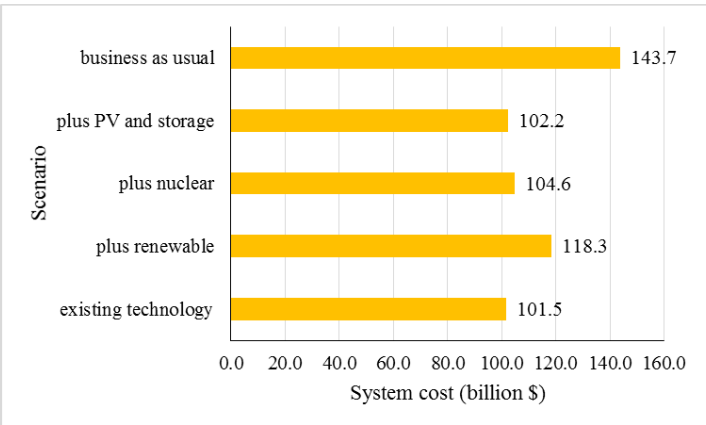

Fig. 7. Total system cost for all scenarios

4. Conclusion

Malaysia could achieve 100% sustainable generation portfolio to meet the demand by 2050 by substituting fossil fuels with indigenous renewable resources. This assessment provides an alternative option for Malaysia's future power generation, whereby Malaysia does not need to embrace nuclear technology, as the base load can be sourced from hydropower while peak load can be generated from solar PV panels. The authors believe that this data could be pursued by the Malaysian Government and utility companies.

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